VOLUME VIII: CHAPTER 6

METHODS FOR ESTIMATING METHANE EMISSIONS FROM DOMESTICATED ANIMALS

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DISCLAIMER

As the Environmental Protection Agency has indicated in Emission Inventory Improvement Program (EIIP) documents, the choice of methods to be used to estimate emissions depends on how the estimates will be used and the degree of accuracy required. Methods using site-specific data are preferred over other methods. These documents are non-binding guidance and not rules. EPA, the States, and others retain the discretion to employ or to require other approaches that meet the requirements of the applicable statutory or regulatory requirements in individual circumstances.

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INTRODUCTION

The purposes of the preferred methods guidelines are to describe emissions estimation techniques for greenhouse gas sources in a clear and unambiguous manner and to provide concise example calculations to aid in the preparation of emission inventories. This chapter describes the procedures and recommended approaches for estimating methane emissions from domesticated animals.

Section 2 of this chapter contains a general description of the domesticated animals source category. Section 3 provides a listing of the steps involved in using the preferred and alternate methods for estimating methane emissions from this source. Section 4 presents the preferred estimation method; Section 5 provides an alternative estimation technique for emissions. Quality assurance and quality control procedures are described in Section 6. References used in developing this chapter are identified in Section 7.

2

SOURCE CATEGORY DESCRIPTION

2.1 EMISSION SOURCES

Methane is a natural by-product of animal digestion. During digestion, methane is produced through a process referred to as enteric fermentation, in which microbes that reside in animal digestive systems break down feed consumed by the animal. Ruminants, which include cattle, buffalo, sheep, and goats, have higher methane emissions than other types of animals because of their unique digestive system. Ruminants possess a rumen, or large "fore-stomach," in which a significant amount of methane-producing fermentation occurs. Non-ruminant domestic animals, such as pigs and horses, have much lower methane emissions than ruminants because much less methane-producing fermentation takes place in their digestive systems. Methane emissions are counted only for domesticated animals; emissions from wild animals are not considered, because such emissions are not the result of human activity.

Methane produced as part of the normal digestive processes of animals result in emissions that account for a significant portion of the global methane budget, about 65-100 million metric tons annually (IPCC, 1997). Approximately 200 species and strains of microorganisms are present in the digestive system of ruminant animals, although only a small portion, about 10 to 20 species, are believed to play an important role in ruminant digestion (Baldwin and Allison, 1983). The microbial fermentation that occurs in the rumen enables ruminant animals to digest coarse plant material that monogastric animals[1] cannot digest.

Methane is produced in the rumen by bacteria as a by-product of the fermentation process. This methane is exhaled or eructated by the animal and accounts for the majority of emissions from ruminants. Methane is also produced in the large intestines of ruminants and is excreted. Non-ruminant herbivores such as horses, mules, rabbits, and pigs have a limited amount of fermentation in the large intestines or ceca. The methane produced in this manner is quite small compared to the amount produced by ruminant animals.

This source category accounts for only some of the many agricultural and forestry activities that emit greenhouse gases. Table 6.2-1 summarizes the agricultural and forestry activities associated with emissions of CO_2, CH_4, and N_2O, and provides a roadmap indicating the chapter in which each activity is addressed.

[1] Monogastric animals have a mouth, esophagus, stomach, small intestines, large intestines, pancreas, and liver (Ensminger, 1983). Examples of monogastric animals include swine, dogs, monkeys, and humans.

Table 6.2-1. GHG Emissions from the Agricultural and Forest Sectors
A check indicates emissions may be significant.

Activity	Associated GHG Emissions and Chapter where these Emissions are Addressed					
	CO_2	Chapter	CH_4	Chapter	N_2O	Chapter
Energy (Farm Equipment)	✔	1	✔	13	✔	13
Animal Production: Enteric Fermentation			✔	6		
Animal Production: Manure Management						
Solid Storage			✔	7	✔	7
Drylot			✔	7	✔	7
Deep Pit Stacks			✔	7	✔	7
Litter			✔	7	✔	7
Liquids/Slurry			✔	7	✔	7
Anaerobic Lagoon			✔	7	✔	7
Pit Storage			✔	7	✔	7
Periodic land application of solids from above management practices					✔	Not included [a]
Pasture/Range (deposited on soil)			✔	7	✔	9
Paddock (deposited on soil)			✔	7	✔	9
Daily Spread (applied to soil)			✔	7	✔	9
Animal Production: Nitrogen Excretion (indirect emissions)					✔	9
Cropping Practices						
Rice Cultivation			✔	8		
Commercial Synthetic Fertilizer Application					✔	9
Commercial Organic Fertilizer Application					✔	9
Incorporation of Crop Residues into the Soil					✔	9
Production of Nitrogen-fixing Crops					✔	9
Liming of Soils	✔	9				
Cultivation of High Organic Content Soils (histosols)	✔	Not included [a]			✔	9
Cultivation of Mineral Soils	✔	Not included [a]				
Changes in Agricultural Management Practices (e.g., tillage, erosion control)	✔	Not included [a]				
Forest and Land Use Change						
Forest and Grassland Conversion	✔	10				
Abandonment of Managed Lands	✔	10				
Changes in Forests and Woody Biomass Stocks	✔	10				
Agricultural Residue Burning			✔	11	✔	11

[a] Emissions may be significant, but methods for estimating GHG emissions from these sources are not included in the EIIP chapters.

2.2 FACTORS INFLUENCING METHANE EMISSIONS FROM DOMESTICATED ANIMALS

The amount of methane produced by domesticated animals depends primarily on the type of animal (e.g., ruminant or non-ruminant), the age and weight of the animal, and the quantity and quality of the feed consumed (IPCC 1997). The quality of the feed depends on the physical and chemical characteristics of the feed, and whether feed additives have been added to promote production efficiency. Other factors that influence methane emissions are the feeding schedule, and the activity level and health of the animal. It has also been suggested that there may be genetic factors that affect methane production.

To describe the methane production by ruminant animals, it is convenient to refer to the portion of feed energy intake that is converted to methane. Higher levels of conversion translate into higher emissions, given constant feed energy intake. Similarly, higher levels of intake translate into higher emissions, given constant conversion. However, these values are not independent—there are interactions between the level of intake and the rate of conversion to methane.

Accounting for the interrelationships among feed characteristics, feed intake, and conversion rates to methane, most well-fed ruminant animals in temperate agriculture systems will convert about 5.5-6.5 percent of their feed energy intake to methane (Johnson et al., 1991). Given this range for the rate of methane formation, methane emissions can be estimated based on the amount of feed energy consumed by the animals. Because feed energy intake is related to production level (*e.g.*, weight gain or milk production), the feed energy intake can be estimated based on production statistics.

The rates of conversion of feed energy to methane for the non-ruminant animals are much lower than those for ruminants. For swine on good quality grain diets, about 0.6 percent of feed energy is converted to methane (Crutzen et al., 1986). For horses, mules, and asses the estimate is about 2.5 percent. While these estimates are uncertain and likely vary among regions, the global emissions from these species are much smaller than the emissions from ruminant animals. Consequently, the uncertainty in these values does not contribute significantly to the uncertainty in the estimates of total methane emissions from livestock.

3

OVERVIEW OF AVAILABLE METHODS

The preferred method described in this chapter is the method used in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1997* (U.S. EPA 1999).

3.1 OVERVIEW OF PREFERRED METHOD

While it is possible to measure methane emissions from cattle directly, it is not practical for preparing an emissions inventory. Given that direct measurements will not be taken, a model has been developed for estimating emission factors for individual animal types. Emissions are first estimated for each type of animal, by multiplying the factors derived from the model by the applicable animal populations. Then, emissions for each animal type are summed to arrive at total emissions for all animal types.

Cattle are large animals, raised in large numbers, and they account for the majority of methane emissions in the U.S. Cattle characteristics and emissions vary significantly by region. Therefore, it was important to develop a good model for cattle, which takes into account the diversity of cattle types and cattle feeding systems in the U.S. Emission factors for other animals were developed using a simple formula based on the amount of feed intake and the percentage of feed intake released

Methods for developing greenhouse gas inventories are continuously evolving and improving. The methods presented in this volume represent the work of the EIIP Greenhouse Gas Committee in 1998 and early 1999. This volume takes into account the guidance and information available at the time on inventory methods, specifically, U.S. EPA's *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions* (U.S.EPA 1998a), volumes 1-3 of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997), and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1996* (U.S. EPA 1998b).

There have been several recent developments in inventory methodologies, including:

- Publication of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1997* (U.S. EPA 1999) and completion of the draft inventory for 1990 – 1998. These documents will include methodological improvements for several sources and present the U.S. methodologies in a more transparent manner than in previous inventories;
- Initiation of several new programs with industry, which provide new data and information that can be applied to current methods or applied to more accurate and reliable methods (so called "higher tier methods" by IPCC); and
- The IPCC Greenhouse Gas Inventory Program's upcoming report on Good Practice in Inventory Management, which develops good practice guidance for the implementation of the 1996 IPCC Guidelines. The report will be published by the IPCC in May 2000.

Note that the EIIP Greenhouse Gas Committee has not incorporated these developments into this version of the volume. Given the rapid pace of change in the area of greenhouse gas inventory methodologies, users of this document are encouraged to seek the most up-to-date information from EPA and the IPCC when developing inventories. EPA intends to provide periodic updates to the EIIP chapters to reflect important methodological developments. To determine whether an updated version of this chapter is available, please check the EIIP site at http://www.epa.gov/ttn/chief/eiip/techrep.htm#green.

as methane. This approach is reasonable because the methane emission characteristics of animals other than cattle are much the same across regions of the U.S. In other words, the variability in emission factors among regions for other animals is much smaller than the variability in emission factors for cattle.

The emission factors for cattle presented in the preferred method were developed using a validated mechanistic model (described in U.S. EPA 1993) of rumen digestion and methane production for cattle feeding systems in the U.S. The digestion model estimates the amount of methane formed and emitted as a result of microbial fermentation in the rumen. The digestion model was linked to an animal production model that predicts growth, pregnancy, milk production and other production variables as a function of digestion products developed by the digestion model. The model evaluates the relationships between feed input characteristics and animal outputs including weight gain, lactation, heat production, pregnancy, and methane emissions. The model has been validated for a wide range of feeding conditions encountered in the U.S.; a total of 32 diets for eight categories of cattle were simulated in 5 regions.

For non-cattle animals, emission factors were obtained from the scientific literature (Crutzen et al, 1986).

3.2 HARMONIZING THIS METHOD WITH ESTIMATES FOR MANURE MANAGEMENT

Emissions estimates for domesticated livestock (covered in this chapter) and manure management (covered in Chapter 7) rely on the same underlying livestock population data and livestock characteristics data. It is important to use the same underlying data to estimate emissions from these two sources. One way to ensure consistency is to use USDA National Agriculture Statistics Service (NASS) data to estimate the livestock populations for both sources. Although the standard categories of livestock types vary between the methods for the two sources, they are internally consistent and rely on the same underlying USDA/NASS population data.

4

PREFERRED METHOD FOR ESTIMATING EMISSIONS

Using the results of the EPA analysis, estimating methane emissions from domesticated animals requires three steps: (1) obtain data on animal populations; (2) identify geographic region and corresponding emissions factor; and (3) multiply each animal population by the appropriate emission factor, and sum the results. These three steps are outlined below.

Step (1): Obtain Required Data

- *Required Data.* The data required are the average animal populations, over the course of the inventory year, for the following animals: cattle (by type; see Table 6-1), buffalo, sheep, goats, swine, horses, mules, and asses. Animal populations fluctuate during the year, in some cases by large amounts. For example, a census done before calving will give a much smaller number than a census done after calving. Thus, the *average* animal population over the course of the inventory year should be used in the estimates (termed here the “annual average population”).

  Of note is that the cattle population data need to be aggregated to the same simplified set of categories shown for the emissions factors in Table 6.4-1. In particular, while cattle may proceed through a variety of management practices from birth to slaughter, this complex set of activities is simplified into emission factors for only two categories of slaughter cattle: weanling and yearling. These emission factors are applied to the total number of heifers and steers <u>slaughtered</u> in a year. Consequently, the number of head slaughtered is the appropriate population parameter to use, and it is not necessary to collect detailed data on growing steers and heifers prior to feedlot placement and steers and heifers in feedlots to make the calculations.

- *Data Source.* Departments within each state responsible for conducting agricultural research are likely to have data on state animal populations. These data are also available on the Internet from the USDA’s National Agricultural Statistics Service (USDA-NASS 1998). When using this data source, a state’s annual average population of a given animal type may be estimated based on (1) the animal population in the state in a given month, (2) the national population of the animal in the same month, and (3) the national population of the animal either six months before or after (as shown in the example below). Additionally, data on state animal populations may be found in the *Census of Agriculture, Volume 1: Geographic Area Series,* published by the Bureau of the Census (e.g., Bureau of the Census 1987).

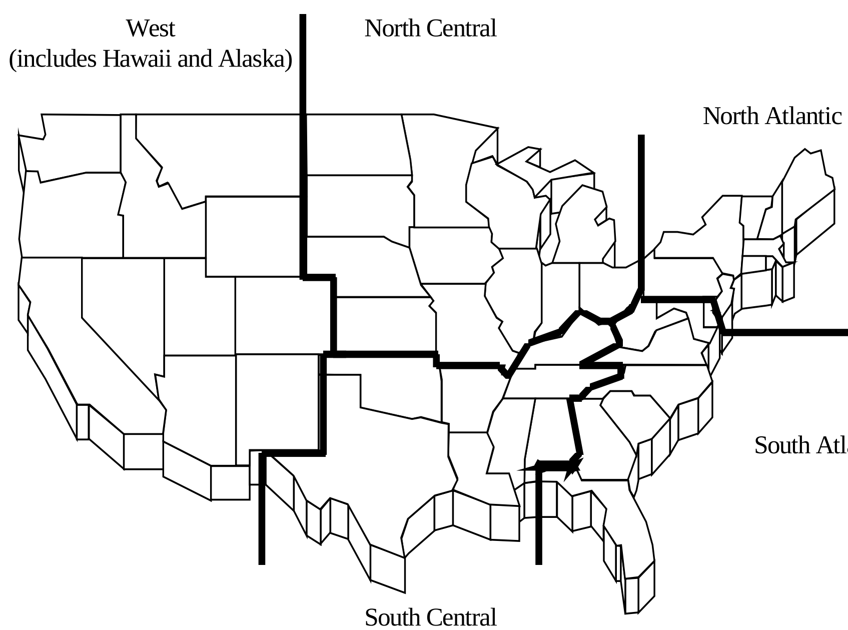
- *Units for Reporting Data.* Animal populations should be reported in number of head.

Example	According to the USDA report *1997 Cattle*, the number of dairy replacement cows 12-24 months in Ohio in January 1997 was **130,000**. The average number of dairy replacement cows 12-24 months in the U.S. in 1997 was [4,037,000 (January value) + 3,600,000 (July value)]/2 = **3,818,500** To estimate the annual average number of dairy replacement cows 12-24 months in Ohio in 1997, scale the January value using a scaling factor of [3,818,500 (national annual average number)]/[4,037,000 (national January value)] = **.9459** The average number of dairy replacement cows 12-24 months in Ohio in 1997 was 130,000 **x** .9459 = **123,000**

Step (2): Identify Geographic Region

- Determine to which of the five geographic regions, defined in Figure 6.4-1, the state belongs. The emission factors corresponding to the region will be used for Step 3.

Figure 6.4-1 Geographic Regions



Step (3): Estimate Methane Emissions

- Multiply each animal population by the appropriate regional emissions factor. Emissions factors for cattle are presented in Table 6.4-1.[2] If using USDA data please refer to Table 6.4-2 for the relationship between USDA cattle categories and the emission factor categories presented in this chapter. (Note that Table 6.4-2 splits the USDA category of "livestock slaughter" as follows: 20 percent to weanling system, and 80 percent to yearling system. If this allocation is not accurate for a given state, state officials should use their judgment to develop a more accurate allocation. Additionally, in some states a significant number of cattle are raised that are subsequently slaughtered in another state. If in the judgment of state officials this movement of cattle among states biases the estimates for a specific state, the more detailed alternative method of calculation can be used.) Emission factors for all other animals are presented in Table 6.4-3.

> ***Example*** Methane emissions from dairy replacement cows 12-24 months in Ohio for 1997 are calculated as follows:
>
> (a) 123,000 head x 126.3 (lbs CH_4/head) = 15,500,000 lbs CH_4
>
> (b) 15,500,000 lbs CH_4 ÷ 2000 (lbs/ton) = **7,750 tons CH_4**

Animal Population (head) x Regional Emissions Factor (lbs. CH_4/head) = Methane Emissions (lbs.)

- For each animal, divide the results by 2000 lbs/ton to obtain tons of methane.

- Sum across all animal types to obtain total methane emissions from domesticated animals, in tons.

- Convert from units of tons to units of metric tons of carbon equivalent. First, multiply the weight of methane in tons by 0.9072 to obtain the mass of methane in metric tons. Then multiply by 21 (the global warming potential of methane) and 12/44 (the ratio of the atomic weight of carbon to the molecular weight of CO_2) to obtain the amount of methane in units of metric tons of carbon equivalent.

[2] EPA is in the process of revising these emission factors.

Table 6.4-2. Emissions Factors for U.S. Cattle by Region (lbs CH_4/head/yr)

Animal Type/Region	North Atlantic	South Atlantic	North Central	South Central	West	National Average[e]
Dairy Cattle						
Replacements 0-12 months[a]	42.9	45.1	41.6	44.7	45.5	43.1
Replacements 12-24 months[a]	128.5	129.1	126.3	135.7	134.6	129.4
Mature Cows	277.4	300.9	246.5	265.7	307.3	269.4
Beef Cattle (Including Range Cattle)						
Replacements 0-12 months[a]	42.2	49.9	44.8	51.9	49.9	49.1
Replacements 12-24 months[a]	140.4	148.5	133.8	148.9	142.7	143.0
Mature Cows	135.3	154.0	130.9	155.9	152.0	146.7
Weanling System Steers/Heifers[b,c]	NA	NA	49.7	52.8	51.7	50.8
Yearling System Steers/Heifers[c,d]	NA	NA	103.4	104.7	104.7	104.1
Bulls	220	220	220	220	220	220

a A portion of the offspring are retained to replace mature cows that die or are removed from the herd (culled) each year. Those that are retained are called "replacements."

b In "weanling systems," calves are moved directly from weaning to confined feeding programs. This system represents a very fast movement of cattle through to marketing. Weanling system cattle are marketed at about 420 days of age (14 months).

c These cattle types are typically not found in the North Atlantic and South Atlantic regions. If an emission factor is needed, one can use the national total emissions factor for these regions.

d "Yearling systems" represent a relatively slow movement of cattle through to marketing. These systems include a wintering over, followed by a summer of grazing on pasture. Yearling system cattle are marketed at 565 days of age (18.8 months).

e National averages are weighted by regional populations as of 1990.

Source: U.S. EPA, 1993, except data for mature dairy cows, which are from U.S. EPA 1998.

Table 6.4-3. Relationship between USDA Cattle Categories and Emission Factor Categories

Emission Category—Animal Type	USDA Category	USDA Source for Data
Dairy Cattle		
Replacements 0-12 months	Heifers for Milk Cow Replacement[a]	*Cattle*-January and July Inventories
Replacements 12-24 months	Heifers for Milk Cow Replacement[a]	*Cattle*-January and July Inventories
Mature Cows	Milk Cows that have calved	*Cattle*-January and July Inventories
Beef Cattle		
Replacements 0-12 months	Heifers for Beef Cow Replacement[a]	*Cattle*-January and July Inventories
Replacements 12-24 months	Heifers for Beef Cow Replacement[a]	*Cattle*-January and July Inventories
Mature Cows	Beef Cows that have calved	*Cattle*-January and July Inventories
Weanling System Steers/Heifers	20% (Heifers + Steers)	*Livestock Slaughter*
Yearling System Steers/Heifers	80% (Heifers + Steers)	*Livestock Slaughter*
Bulls	Bulls 500 lbs +	*Cattle*-January and July Inventories

[a] The USDA's reported heifer count is the number of replacements 12-24 months old. It is assumed that there will be an equal number of replacements 0-12 months old.

Table 6.4-4
Enteric Fermentation Emission factors for Animals Other than Cattle (lbs CH_4/head/year) (All Regions)

Animal Type	Feed Intake (MJ/h/day)	Methane Conversion (%)	Emission factors (lbs/h/yr)
Sheep	20	6%	17.6
Goats	14	5%	11.0
Swine	38	0.6%	3.3
Horses	110	2.5%	39.6
Mules/Asses	60	2.5%	48.5

Source: Crutzen et al. (1986).

Table 6.4-5
Emission factors for U.S. Cattle by Region (lbs CH_4/head/yr)
Mechanistic Model vs. IPCC Model

Animal Type/Region	National Average	
	Mechanistic Model	IPCC Method
Dairy Cattle		
Replacements 0-12 months	43.1	46.9
Replacements 12-24 months	129.4	127.5
Mature Cows	252.1	248.7
Beef Cattle		
Replacements 0-12 months	49.1	51.1
Replacements 12-24 months[a]	143.0	121.5
Mature Cows	146.7	143.9
Weanling System Steers/Heifers[b]	50.8	80.2
Yearling System Steers/Heifers	104.1	113.7
Bulls[c]	220.0	223.4

[a] The IPCC emission factors for beef replacements 12-24 months were calculated to reflect the net energy for growth for medium frame heifer calves as cited in NRC (1984).
[b] Feed and growth rates for weanlings in the U.S. are different from rates in the rest of the world; the IPCC method does not account for these differences, which could explain the differences in the estimates obtained from the two models.
[c] The IPCC emission factors for bulls were calculated to reflect the intake requirements as cited in NRC (1984).

5

ALTERNATE METHOD FOR ESTIMATING EMISSIONS

The IPCC Greenhouse Gas Inventory Program is currently developing an alternative method for emissions from cattle and sheep. This method will be published in May 2000 as part of the good practice guidance for implementation of the 1996 IPCC Guidelines.

6

QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) and quality control (QC) are essential elements in producing high quality emission estimates and should be included in all methods to estimate emissions. QA/QC of emissions estimates are accomplished through a set of procedures that ensure the quality and reliability of data collection and processing. These procedures include the use of appropriate emission estimation methods, reasonable assumptions, data reliability checks, and accuracy/logic checks of calculations. Volume VI of this series, *Quality Assurance Procedures*, describes methods and tools for performing these procedures.

6.1 DATA ATTRIBUTE RANKING SYSTEM (DARS) SCORES

DARS is a system for evaluating the quality of data used in an emission inventory. To develop a DARS score, one must evaluate the reliability of eight components of the emissions estimate. Four of the components are related to the activity level (e.g., the domestic animal populations). The other four components are related to the emission factor (e.g., the amount of methane emitted by a given type of domestic animal). For both the activity level and the emission factor, the four attributes evaluated are the measurement method, source specificity, spatial congruity, and temporal congruity. Each component is scored on a scale of zero to one, where one represents a high level of reliability. To derive the DARS score for a given estimation method, the activity level score is multiplied by the emission factor score for each of the four attributes, and the resulting products are averaged. The highest possible DARS composite score is one. A complete discussion of DARS may be found in Chapter 4 of Volume VI, *Quality Assurance Procedures*.

The DARS scores provided here are based on the use of the emission factors provided in this chapter, and activity data from the US government sources referenced in the various steps of the methodology. If a state uses state data sources for activity data, the state may wish to develop a DARS score based on the use of state data

TABLE 6.6-1

DARS SCORES: CH_4 EMISSIONS FROM CATTLE (PREFERRED METHOD)

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	4	Because the emission factors are not based on measurement, the highest possible score is 5. Since the factors are derived from a model, applying the DARS formula the score would be 3; however, the model is sophisticated.	8	Data on annual average animal populations are estimated based on state and national data.	0.32
Source Specificity	10	The emission factors were developed specifically for the intended emission source (i.e., eight categories of cattle were modeled).	9	The activity measured, average animal population, is very closely correlated to the emissions activity.	0.90
Spatial Congruity	7	The emission factor was developed for five regions of the U.S. (each larger than a state). However, spatial variability for the emissions factor within each region is assumed to be moderate.	10	States use state-level activity data to estimate state-wide emissions.	0.70
Temporal Congruity	7	The emission factors are based on a model, not on measured emissions over a particular time frame. Temporal variability is expected to be low to moderate.	10	States use annual activity data to estimate annual emissions.	0.70
				Composite Score	**0.66**

TABLE 6.6-2

DARS SCORES: CH_4 EMISSIONS FROM DOMESTICATED ANIMALS OTHER THAN CATTLE (PREFERRED METHOD)

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	3	Because the emission factor is not based on measurement, the highest possible score is 5. Since the factor is derived from a model, applying the DARS formula the score would be 3. The model uses only one emission factor for each species (i.e., it does not adjust for animal mass).	8	Data on annual average animal populations are estimated based on state and national data.	0.24
Source Specificity	10	The emission factors were developed specifically for the intended emission source (i.e., an emission factor was developed for each species).	9	The activity measured, average animal population, is very closely correlated to the emissions activity.	0.90
Spatial Congruity	7	A single global emission factor was developed for each species. Spatial variability for the emission factors is assumed to be moderate.	10	States use state-level activity data to estimate state-wide emissions.	0.70
Temporal Congruity	7	The emission factors are based on a model, not on measured emissions over a particular time frame. Temporal variability is expected to be low to moderate.	10	States use annual activity data to estimate annual emissions.	0.70
				Composite Score	**0.64**

7

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